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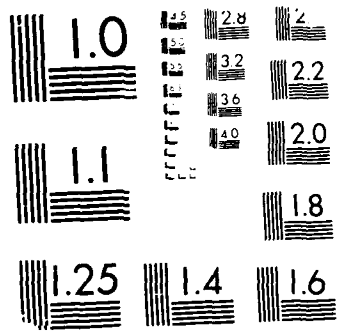

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FOREIGN TECHNOLOGY DIVISION

EFFECT OF A SHEAR LAYER ON THE STABILITY OF AN AXISYMMETRIC EXTERNAL COMPRESSION AIR INTAKE

by

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EDITED TRANSLATION

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EFFECT OF A SHEAR LAYER ON THE STABILITY OF AN AXISYMMETRIC EXTERNAL COMPRESSION AIR INTAKE

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ABSTRACT

This paper presents the effect of six shear layers with strength ranging from 5-11% entering the lip in various positions on the stability of a variable center cone external compression air intake under the condition of a M 1.72 incident stream.

It was experimentally proven that a shear layer below 10% in strength entering the axisymmetric intake near the lip did not cause boundary layer separation inside the intake cowl. A shear layer up to 11% in strength could enter the intake duct in any position at its entrance without causing buzz. The literature shows a shear layer with 6-7% strength can lead to a buzz in a two-dimensional air intake. Thereby, it was demonstrated that an axisymmetric intake duct has a higher resistance to buzz caused by the shear layer.

I. Introduction

The stable operating range is an important characteristic for a supersonic air intake under subcritical conditions. In the past decades, many scholars had conducted research on this subject and different theories were introduced. This paper studies the effect of a shear layer on the stability of an axisymmetric external compression air intake.

Received in December, 1982

Ferri's shear layer theory which is well recognized has been verified by many investigators [1]. His theory states: When a shear layer which is formed by the intersecting of shock waves enters the air intake near the cowl lip, it causes a boundary layer, separation from the inside cowl surface and induces a buzz in the intake. This is the well known Ferri criterion.

In the late 1960's in the UK, Fisher and others successfully applied Ferri's criterion to the design of the two-dimensional air intake for the supersonic transport "Concorde"[2]. They pointed out that a buzz could occur when the shear layer with a strength of not less than 6~7% entered the lip of the air intake. The strength is defined as the ratio of the total pressure of the up-stream before the interception of the shock waves. Their report also pointed out that the tendency of the separation of the boundary layer on the inside cowl surface increased with increasing shear layer strength and decreased with increasing distance between the shear layer and the cowl.

The Fisher's result is very valuable for a two-dimensional air intake. However, it cannot directly solve similar problems of axisymmetric air intakes. There are differences between these two types of air intakes, because their reactions to a shear layer and other details are quite different. This paper presents the effect of a shear layer on the subcritical stability of the axisymmetrical air intake.

II. Shear layer of a typical biconic intake /57

Let us first study the behavior of a biconical air intake with a maximum incident flow of $M = 2.2$. The half angles of first and second cone of the intake duct center cone are 17.5° and 25°, respectively. At an incident flow of $M = 2.2$, the first oblique wave will seal the intake. At $M < 2.2$, the second shock will cover the intake. When M is between 1.8 and 2.2, theoretically there are three different situations in this critical and subcritical operating condition: (1) critical, (2) slightly sub-critical and (3),

comparatively large sub-critical (Figure 1).

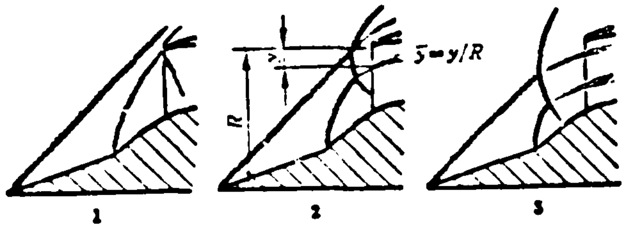

Figure 1. Shock systems of a biconic intake

Now, based on the structures of the above wave systems, let us calculate the shear layer strength. The definition of a shear strength can be expressed as follows:

$$S = \frac{\text{total pressure difference of the two sides of shear flow}}{\text{total pressure of incoming stream}} \times 100\%$$

Figure 2 shows the calculated results. In addition, the distance "y" (or the relative distance "$\bar{y}$") between the second shock shear layer and the cowl lip is one of the important factors affecting the magnitude of the shear layer. "y" or "$\bar{y}$" is a *function of the Mach number and the coefficient of flow* ϕ (see Figure 3).

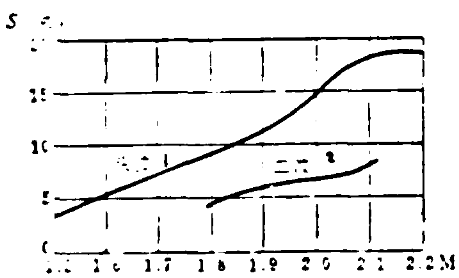

Figure 2. Variation of strength S_v with M
1--first shock; 2--second shock

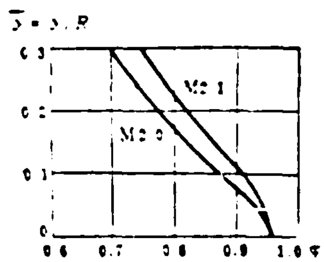

Figure 3. Variation of $\bar{y}$ with ϕ

From the calculated results, we can see when M = 1.8-2.1, the shear layers of the biconic air intake have the following two basic characteristics:

(1) The shear layer of the first shock wave is stronger. Its strength ranges between 8.8-17.8%. Nevertheless, in the vicinity of critical conditions, this stronger shear layer will not enter the cowl lip. It will enter the cowl lip only under comparatively large subcritical conditions.

(2) The strength of the shear layer of the second shock wave is between 4.8~8.0%. It enters the cowl lip at the beginning of subcritical conditions. The maximum value occurs when the flow coefficient $\phi < 0.9$ and distance $\bar{y} > 0.09$.

Based on experimental data published abroad, we noticed that the weakest shear layer to cause the buzz of an axisymmetric air /58 intake had a strength of 14.2% [3]. Based on this fact, it is believed that any shear layer with strength greater than 14.2% should not be allowed to enter the cowl lip in our analysis. This paper focuses on the study of the correlation between the shear layer and the axisymmetric air intake while the shear layer strength is below 14.2%, yet much higher than the Fisher's 6~7%.

III. Test model and equipment

The experiment model used was the single cone external compression air intake type with an adjustable apex angle. The position of the cone axis could be adjusted. This model could generate shear layers with strengths of 5.2, 6.1, 7.9, 9.1, 10.2 and 11%, respectively. The shear layer could also be allowed to enter the cowl lip from a different distance "y". The inlet diameter of the model ϕ = 106 mm; wind tunnel test section, 300x300 mm; and $R \approx 2 \times 10^6$ as calculated from the intake diameter of the model. Along the model flow range, four dynamic pressure transducers and ports for measuring static pressure and total pressure were installed in order to measure the static and the dynamic parameters under different conditions. Figure 4 shows the sketch of the model.

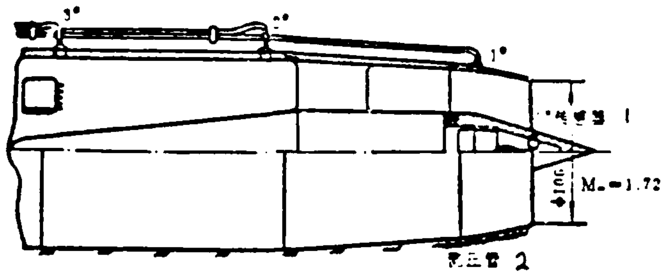

Figure 4. Model of intake
1--transducer; 2--pressure measuring tube

IV. Test results

(1) Before and after the shear layer with a strength of 11% entered the cowl lip, the cross section of the air intake exit end did not show any static pressure fluctuation.

Six cones with different apex angles were, respectively, positioned according to design so that each shock wave would cover the intake. During experimentation, each shear layer of the six different strengths at the cowl lip were either allowed or not allowed to enter the intake duct. At the same time, we closely observed if there is any apparent change in the working condition of the air intake, especially any change in the static pressure fluctuation on the exit cross section. It was found when a shear flow with any one of these six strengths entered the air intake at the cowl lip, the air intake did not show any sign of buzzing. Only when the shock wave was pushed a distance from the cowl lip, the intake began to buzz, i.e., the positive shock wave started fluttering, and the static pressure at the exit increased significantly. In other words, there existed a maximum stable subcritical operating condition. See Table 1.

Figure 5 shows the plot of the existing static pressure at the exit of the air intake duct with 24° apex angle when $1 > \phi > 0.93$. Although the shear layer with a strength of 10.7% already entered the cowl lip, there was no apparent change of the pressure fluctuation in the supercritical condition.

TABLE 1. Parameters at the limit of stable subcritical operation

1. [illegible] / 2. [illegible]	[illegible]	24°	20°	18°	[illegible]
3 [illegible] S_w %	[illegible]	[illegible]	9.4	7.8	6.1
4 [illegible]	11	11	13	5	4
5 [illegible] ϕ	[illegible]	[illegible]	0.91	[illegible]	[illegible]
6 [illegible]	[illegible]	[illegible]	8.2	3.6	3.0
7 [illegible] $\frac{\Delta P_M}{P}$	[illegible]	1~2	1~2	1~2	1~2
8 [illegible] $\frac{\Delta P_M}{P}$ %	1~2	1~2	1~2	1~2	1~2

1--description; 2--apex angle; 3--shear layer strength during testing; 4--maximum positive shock wave stable distance (from cowl lip); 5--ditto, coefficient of flow; 6--ditto, shear layer distance; 7--pressure fluctuation at exit before shear layer entering the intake; 8--pressure fluctuation at exit after shear layer entering the intake

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Figure 5. Pressure fluctuation at exit of 24° cone model.
1--supercritical condition before shear layer entering the intake ϕ = 1; 2--stable subcritical condition after the shear layer entering the intake ϕ = 0.98-0.92; 3--buzz ϕ = 0.64

In short, when a detectable unsteady flow begins to appear in the air intake, the shear layer has already departed from the cowl lip for a considerable distance. Therefore, it is reasonable to conclude that the unsteady stream is not caused by the shear layer, but is possibly caused by the separation of the boundary layer of the central body.

(2) The strongest shear layer, when entering the cross section of the intake duct from different distances, does not induce buzzing.

TABLE 2. Results obtained with the strongest shear layer entering the cowl at different distances from lip

1. [illegible]	2. [illegible]								3. [illegible]
4. [illegible]	0	2	3	4	5	7	[illegible]	[illegible]	[illegible]
5. [illegible]	1~2	1~2	1~2	1~2	1~2	1~2	1~2	1~2	1~2
6. [illegible]	7 [illegible]								

1--test method; 2--gradually retracting the center cone to maintain the critical condition; 3--center cone fixed, pushing out the positive shock wave step by step; 4--shear layer distance, y (mm); 5--pressure fluctuation at the exit; 6--intake duct working condition; 7--no detectable buzz

We used two different methods to control the entrance distance "y" of the shear layer. First, we gradually retracted the center cone to maintain the critical condition. Secondly, at a fixed cone position, we pushed the positive shock wave toward the cone apex step by step. Thus, the distance "y" between the shear layer and the cowl lip gradually increased to approach the center cone. Table 2 shows the results obtained with the strongest shear layer entering the cowl at different distances from the lip.

No buzz was induced when the shear layer entered at any position of the lip cross section of our experimental air intake assembly.

We conducted similar experiments for the other five shear layers of different strengths. The results were practically the same as above. Therefore, the six shear layers of different strengths in this investigation did not induce the air intake buzzing regardless of the distance of entrance from the lip.

(3) Characteristics of the flow separation on the inside cowl surface.

It is generally believed that the buzz induced by the shear layer is caused by the separation of the boundary layer on the inside cowl surface. Therefore, the presence of the separation zone is a necessary condition to cause this type of unsteady flow. In our

experiment, we noticed that the shear layer did not have the capability to initiate a buzz in the air intake. Therefore, it was important to investigate whether or not the shear layer initiated the boundary layer separation on the inside cowl surface. We studied the characteristics of boundary layer separation on the inside cowl /60 surface with the shear layer of different strengths entering the lip at various distances. Figure 6 shows the test results. In this diagram, there are 16 test locations. When the strength was less than 10%, no separation of the boundary layers inside the cowl lip was observed at seven locations. The corresponding static pressure fluctuations also did not reveal any abnormalities. The amplitudes of the pressure fluctuations ranged only between 1 ~ 2% of the total pressure of the incoming stream.

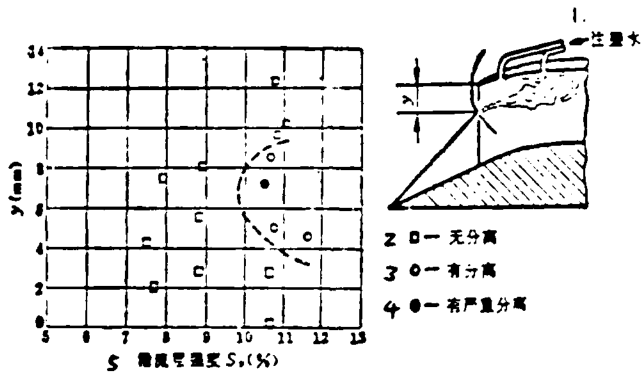

Figure 6. Effect of strength S_v and distance y on cowl lip separation.

1--ink injection; 2--□ - no separation; o - separation;
● - serious separation; 5--strength of shear layer S_v(0/0)

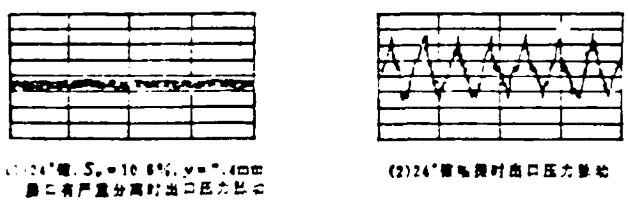

Figure 7. Pressure fluctuations at exit of 24° cone model.
(1) without end (2) with buzz
1--24° cone, pressure fluctuations at exit when serious separation occurs at the cowl lip;
2--24° cone pressure fluctuations at exit during buzzing

When the shear layer strength was greater than 10%, four out of nine test locations showed separations on the cowl lip. One of them, S_v = 10.6% and y $\approx$ 7.4 mm, was quite serious. However, even when a boundary layer separation zone exists, the static pressure fluctuations at the model's exit remains still very small (Figure 7). This observation indicates that buzz will not be induced when the boundary layer separation does not seriously block the intake.

Moreover, we observed that there was a certain distance at which the shear layer would cause the most significant effect. Outside the range of y = 5 to 9 mm, the shear layer with a strength of 11% could not cause the separation of the boundary layer. In this investigation, the most significant effective distance is $\bar{y}$ = y/R = 10~18%.

This investigation has proven that the shear layer with a strength (S_v) of 11% will not damage an axisymmetric intake duct. Based on this observation, we can predict that in an axisymmetric air intake, the shear layer strength shall be higher than 11% before it can induce a Ferri type unsteady flow.

As it should be, for the air intake of a full size engine, it is not a simple problem to determine the maximum tolerable shear layer. Other factors must also be considered. Hence, the results of this investigation should not be considered as a unique criterion. However, based on our investigation and other published results of two-dimensional air intakes, we can conclude that the axisymmetric air intake can stand higher strength shear flow than the two-dimensional air intakes.

V. Conclusions /61

(1) In order to cause a separation of the boundary layer on the inside cowl surface of an axisymmetrical air intake, the shear layer strength has to exceed 10%. However, no buzz can be induced if the separation does not seriously block the stream.

(2) A significant separation of the boundary layer occurs only when the shear layer enters the cowl at a certain distance from the lip. In this investigation, we find that the distance is between 10 ~ 18% of the cowl radius, i.e., 5~9 mm.

(3) A shear layer with a strength of 11% will not cause the air intake to buzz. The axisymmetric air intake can stand a higher shear layer strength than the two-dimensional air intake.

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